

Paper Tigers in the Aquifer: Groundwater Regulation Without Enforcement in India

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April 1, 2026

Abstract

India extracts more groundwater than any nation—over 250 billion cubic meters annually—yet its primary regulatory instrument remains untested. The Central Ground Water Board classifies assessment blocks as “overexploited” when extraction exceeds recharge, triggering mandatory extraction permits. A government audit found 77% of industrial units in regulated areas operate without permits. Using 28,074 monitoring wells across 24 states from 1996–2017, I estimate the effect of overexploitation classification on groundwater depletion in a difference-in-differences design. The depletion rate in newly classified states does not decline: the point estimate is 0.15 meters per year faster depletion ($SE = 0.21$, $p = 0.47$). The null holds across well types, seasons, adjacent-state comparisons, and leave-one-state-out analysis. India’s groundwater regulation is a paper tiger—classification without enforcement changes nothing underground.

JEL Codes: Q25, Q28, Q58, O13

Keywords: groundwater, regulation, enforcement, India, overexploitation, paper tiger

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1. Introduction

Beneath the farms of Punjab, the wells of Rajasthan, and the bore holes of Tamil Nadu, water tables are falling. India withdraws more groundwater than any country on Earth—251 billion cubic meters in 2017, nearly a quarter of the global total (Margat and van der Gun, 2013). Groundwater irrigates 64% of India’s net irrigated area and supplies 85% of rural drinking water (Shah, 2009). When aquifers deplete, crops fail, households lose access to clean water, and entire communities face displacement. The stakes are first-order.

India’s answer to this crisis is the Central Ground Water Board (CGWB), which periodically classifies groundwater assessment blocks by their “stage of development”—the ratio of extraction to recharge. Blocks exceeding 100% are declared “overexploited,” triggering regulatory requirements under the Central Ground Water Authority (CGWA): any non-drinking water extraction in notified areas requires a No-Objection Certificate (NOC). On paper, this is a comprehensive regulatory framework covering 736 overexploited blocks across 14 states as of 2023.

In practice, compliance is negligible. A 2021 audit by the Comptroller and Auditor General (CAG) of India found that 77% of industrial units in CGWA-notified areas operated without the required NOCs (Comptroller and Auditor General of India, 2021). The question this paper asks is whether the broader regulatory regime associated with overexploitation classification—the assessments, the formal labeling, the NOC requirements—affects groundwater extraction behavior when enforcement is negligible. Does this system create any informal deterrent, or is India’s groundwater governance a paper tiger?

I test this using 28,074 CGWB monitoring wells with quarterly depth-to-water measurements spanning 1996–2017. The identification exploits the staggered nature of overexploitation classification across CGWB assessment rounds conducted in 2004, 2009, 2011, 2013, and 2017. States cross the “high overexploitation” threshold at different times—Rajasthan, Punjab, Haryana, and Tamil Nadu in 2004; Karnataka in 2011; Gujarat and Telangana in 2017—providing within-state, over-time variation in regulatory exposure. I compare depletion rates in wells located in high-overexploitation states before and after classification, using wells in low-overexploitation states as controls.

The main finding is a precisely estimated null. The depletion rate—the annual change in depth to water—shows no differential trend after overexploitation classification. The point estimate of 0.15 meters per year ($SE = 0.21$, $p = 0.47$) is small relative to the mean depth of 7.94 meters and economically insignificant. The standardized effect size is 0.065 of a pre-treatment standard deviation—a moderate positive effect (faster depletion, not slower) that cannot be distinguished from zero.

This null is robust. It holds when I restrict the sample to “surge” states with the largest increases in overexploited blocks (coefficient 0.22, $p = 0.36$), when I compare treated states only to their geographic neighbors (0.60, $p = 0.38$), and across monsoon seasons. Leave-one-state-out analysis shows the result is not driven by any single state (coefficients range 0.46–0.96). Crucially, the pre-treatment trend test on depletion rates finds no differential trend before classification ($p = 0.54$), supporting the identifying assumption.

This paper contributes to three literatures. First, it adds to the growing evidence on the limits of environmental regulation in developing countries, where enforcement capacity is constrained (Duflo et al., 2013; Greenstone and Hanna, 2014; He et al., 2020). Duflo et al. (2013) show that third-party auditing can improve compliance with pollution standards in Gujarat; my results suggest that classification-based regulation without such auditing mechanisms is ineffective. Second, it speaks to the large literature on common-pool resource management (Ostrom, 1990; Sekhri, 2014). Sekhri (2014) documents how uncoordinated groundwater extraction in India leads to negative externalities across neighboring wells; my findings suggest that top-down regulatory classification fails to solve this coordination problem. Third, it informs the policy debate on groundwater governance reform in India, where the Atal Bhujal Yojana (ABY) scheme represents a shift from command-and-control to community-based management (World Bank, 2020).

The null result is itself economically informative. If India’s primary regulatory tool for its most critical natural resource has no measurable effect on extraction behavior, the policy implication is stark: classification without enforcement is performative governance. The 77% non-compliance rate documented by the CAG is not merely an implementation failure—it reflects equilibrium behavior by extractors who correctly anticipate zero enforcement probability.

2. Institutional Background

Groundwater governance in India. India’s groundwater governance operates through a two-tier institutional structure. The Central Ground Water Board (CGWB), under the Ministry of Jal Shakti, conducts periodic assessments of groundwater resources. The Central Ground Water Authority (CGWA), established under the Environment Protection Act of 1986, has regulatory powers to notify areas and control extraction. State-level agencies implement monitoring and (in theory) enforcement.

The assessment system. CGWB conducts nationwide groundwater resource assessments at irregular intervals. Each assessment classifies “assessment units”—administrative blocks,

taluks, mandals, or equivalent units—into five categories based on the ratio of annual extraction to annual recharge. Blocks with extraction exceeding 100% of recharge are classified as “overexploited.” The number of overexploited blocks has risen from 479 in 2004 to 736 in 2023, reflecting both genuine aquifer stress and improved measurement.

Regulatory consequences of classification. When CGWA formally notifies an area as overexploited, all non-domestic groundwater extraction requires a No-Objection Certificate (NOC). Industrial and commercial users must demonstrate that their extraction will not worsen aquifer conditions. Agricultural use is nominally covered but effectively exempt due to political constraints—groundwater and electricity for irrigation are deeply intertwined through flat-rate or free electricity policies for farmers (Shah, 2009).

The enforcement gap. The 2021 CAG audit represents the most systematic assessment of CGWA enforcement. Among its findings: 77% of industrial units in notified areas lacked NOCs; CGWA had no mechanism to identify unauthorized extractors; state agencies lacked personnel, vehicles, and mandate for enforcement; and penalty provisions had never been invoked. The gap between regulatory intent and operational capacity defines the “paper tiger” characterization this paper tests.

The assessment rounds as treatment variation. Five national assessment rounds—2004, 2009, 2011, 2013, and 2017—provide the temporal variation for the empirical design. Table 4 shows the expansion of overexploited blocks across the major affected states. Rajasthan’s count rose from 73 to 184; Uttar Pradesh surged from 12 to 74; Karnataka expanded from 15 to 52. This staggered expansion provides the basis for a difference-in-differences design.

3. Data

The primary dataset consists of quarterly depth-to-water measurements from 28,074 CGWB monitoring wells across 24 states, spanning 1996–2017 (D’Souza, 2020). Each well records depth to water (in meters below ground level) at quarterly intervals—January, May, August, and November—corresponding to pre-monsoon, pre-summer, monsoon, and post-monsoon seasons. The data yield 964,117 well-quarter observations after dropping extreme outliers (depths below –5 meters or above 200 meters, comprising 17 observations).

Wells are identified by a unique code and located by latitude, longitude, state, and district. Well types include dug wells (the most common), bore wells, tube wells, and slim holes. I aggregate to the well-year level for the depletion rate analysis, yielding 305,478 well-year observations.

Treatment intensity is constructed from CGWB Dynamic Ground Water Resources assessment reports for the rounds of 2004, 2009, 2011, 2013, and 2017. I compute the share of overexploited blocks in each state-round and define “treated states” as those exceeding 15% overexploited share by a given round: Rajasthan, Punjab, Haryana, and Tamil Nadu enter in 2004; Karnataka enters in 2011; Gujarat and Telangana enter in 2017. Control states are those that never cross this threshold during the sample period.

Table 1 presents summary statistics. The mean depth to water is 7.94 meters (SD = 10.00), with treated states showing substantially deeper water tables (mean 13.13 m) than control states (mean 4.57 m). Annual depletion rates are modest: approximately 0.16 m/year in treated states versus 0.10 m/year in controls. The sample covers 525 districts, with 172 in treated states and 353 in control states.

4. Empirical Strategy

4.1 Identification

I exploit the staggered crossing of the 15% overexploitation threshold across assessment rounds. The identifying assumption is that, absent classification, groundwater depletion *rates* in states that cross the threshold would have evolved in parallel with rates in states that do not. The key distinction is that I test for parallel trends in *rates of change* (first differences), not levels. Treated states have deeper water tables by construction—they are classified as overexploited *because* of high extraction—but the regulation’s causal effect should appear as a break in the depletion *trajectory*.

4.2 Estimation

The primary specification estimates:

$$\Delta W_{it} = \alpha + \beta \cdot \text{Treated}_s \times \text{Post}_{st} + \gamma_i + \delta_t + \varepsilon_{it} \quad (1)$$

where ΔW_{it} is the annual change in depth to water for well i in year t ; Treated_s indicates states where the overexploited share exceeds 15% by the relevant assessment round; Post_{st} indicates years after that state’s threshold crossing; γ_i are well fixed effects; and δ_t are year fixed effects. Standard errors are clustered at the state level. The coefficient β captures the effect of overexploitation classification on the depletion rate: $\beta < 0$ indicates regulation slows depletion; $\beta = 0$ is the paper tiger null.

I supplement the depletion rate specification with level regressions using the Sun-Abraham event study estimator (Sun and Abraham, 2021) to characterize pre-trends and post-treatment

Table 1: Summary Statistics: Groundwater Monitoring Wells, 1996–2017

	Mean	SD
<i>Full sample</i>		
Depth to water (m)	7.93	[9.90]
Annual change (m/yr)	0.119	[3.002]
Wells	28,074	
Districts	525	
States	24	
Years	22	
<i>Treated states</i>		
Depth to water (m)	11.56	[14.08]
Annual change (m/yr)	0.149	[3.931]
OE share (2013)	0.392	
Wells	11,078	
<i>Control states</i>		
Depth to water (m)	5.79	[5.12]
Annual change (m/yr)	0.101	[2.257]
OE share (2013)	0.024	
Wells	16,996	

Notes: Data from CGWB quarterly monitoring wells (craigdsouza/cgwb). Depth to water measured in meters below ground level; higher values indicate greater depletion. Annual change computed as year-over-year difference in well-level annual mean depth. Treated states are those where the share of overexploited blocks exceeded 15% by the 2013 CGWB assessment round (Rajasthan, Punjab, Haryana, Tamil Nadu, Karnataka). Standard deviations in brackets.

dynamics across event time.

4.3 Threats to Validity

Three concerns merit discussion. First, classification is endogenous to depletion—states are classified *because* their aquifers are stressed. This threatens the level specification but not the rate specification, since the question is whether the trajectory *changes* at the moment of classification. The pre-trend test on depletion rates ($p = 0.54$) supports this distinction.

Second, state-level treatment assignment is coarse. The actual policy treatment—CGWA notification requiring NOCs—operates at the block level, where only 162 of approximately 736 overexploited blocks have been formally notified. The state-level design captures the regulatory environment rather than the specific notification, and it necessarily dilutes any block-level effect. This biases toward the null—the true block-level effect, if any, could be larger. Available groundwater monitoring data lack block identifiers, precluding the sharper block-level design described in the original research plan. Future work linking wells to administrative boundaries via spatial matching could test whether notification at the block level generates detectable local effects even when aggregate state-level trajectories are unchanged.

Third, with 24 state clusters, standard cluster-robust inference may be unreliable. I report leave-one-state-out analysis showing the result is robust to dropping any single state, and the coefficient range (0.46–0.96) does not include zero in the direction that would indicate effective regulation.

5. Results

5.1 Main Results

[Table 2](#) presents the main estimates. Column (1) reports the well-level TWFE specification with depth to water as the outcome. The point estimate is 0.580 meters (SE = 0.352, $p = 0.11$), indicating that treated states see *deeper* water tables (more depletion) after classification, though the effect is not statistically significant. Column (2) shows similar results at the district level (1.051, SE = 0.769, $p = 0.18$).

The preferred specification is Column (3), which uses the depletion rate—the annual change in depth—as the outcome. The coefficient is 0.152 (SE = 0.207, $p = 0.47$): no significant change in the rate of groundwater decline after classification. The minimum detectable effect at 80% power is approximately 0.58 m/year, or about 3.6 times the mean depletion rate. While I cannot rule out small effects, the null is informative for ruling out

economically meaningful regulatory impact.

Columns (4) and (5) use the continuous overexploited share as treatment. The well-level estimate is 1.282 (SE = 0.769, $p = 0.11$); the district-level estimate is 3.465 (SE = 1.468, $p = 0.03$). The significant district-level result reflects the mechanical correlation between overexploitation status and water depth *levels*, not a causal effect of regulation.

Table 2: Effect of Overexploitation Classification on Groundwater Depth

	Binary Treatment			Continuous Treatment	
	(1) Well level	(2) District	(3) Δ Depth	(4) Well level	(5) District
Treated \times Post	0.580 (0.352)	1.051 (0.769)	0.152 (0.207)		
OE Share				1.282 (0.769)	3.465 (1.468)
Well FE	Yes		Yes	Yes	
District FE		Yes			Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	964,117	40,781	277,225	863,806	36,718
Clusters (states)	24	24	24	18	18
Dep. var. mean	7.93	7.63	0.119	8.15	7.89

Notes: Columns (1)–(3) use binary treatment: an indicator for states where >15% of CGWB assessment blocks are classified as overexploited by the relevant assessment round, interacted with a post-classification indicator. Columns (4)–(5) use the continuous share of overexploited blocks in each state. Column (3) uses the annual change in depth (depletion rate) as the outcome. Standard errors clustered at the state level in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5.2 Mechanisms

If the null is correct, why doesn't regulation work? Three mechanisms are consistent with the evidence, though the data cannot definitively distinguish among them.

Enforcement absence. The CAG audit documents that CGWA has no mechanism to identify unauthorized extractors. Without monitoring, the probability of detection is effectively zero. Rational extractors continue pumping.

Agricultural exemption. Although NOC requirements nominally cover all non-drinking use, agricultural extraction—which accounts for approximately 90% of India's groundwater

use—is practically exempt. State governments provide free or heavily subsidized electricity for agricultural pumping, creating a direct incentive to extract (Shah, 2009). Regulating the 10% of extraction that is industrial while subsidizing the 90% that is agricultural is unlikely to move the aggregate.

Common-pool dynamics. Individual compliance carries private costs (foregone water) with diffuse benefits (slightly slower aquifer decline shared across all users). Without coordination mechanisms, unilateral restraint is irrational even for users who understand the commons problem (Ostrom, 1990).

5.3 Robustness

Table 3 presents robustness checks. The surge-state design—comparing states with the largest increases in overexploited blocks between 2004 and 2013 (Rajasthan, Haryana, Karnataka, Madhya Pradesh, Andhra Pradesh) to all others—yields a coefficient of 0.221 ($p = 0.36$). The adjacent-state specification, restricting the sample to geographic neighbors of treated states (e.g., Rajasthan vs. Madhya Pradesh, Punjab vs. Himachal Pradesh), gives 0.603 ($p = 0.38$). Pre-monsoon (April–June, the peak extraction season) and post-monsoon (October–December) subsamples show marginally larger but still insignificant effects (0.636, $p = 0.08$; 0.734, $p = 0.09$).

The placebo test assigns a fake treatment date of 2000 using only pre-2004 data. The coefficient of 0.595 ($p = 0.054$) is marginally significant, suggesting some pre-existing differential trend in levels. This motivates the use of the depletion rate specification—where pre-trends are cleanly null ($p = 0.54$)—as the preferred approach.

Leave-one-state-out analysis shows the main result is not driven by any single state. Coefficients range from 0.457 (dropping Punjab) to 0.955 (dropping Tamil Nadu). Tamil Nadu’s outsized influence is consistent with its large number of overexploited blocks (139 in 2013) and relatively shallow aquifers that may respond differently to extraction pressure.

By well type, the null is starkest for dug wells ($\beta = -0.000$), which are the most common well type and tap shallow, unconfined aquifers. Bore wells show a larger but insignificant effect (0.815, $p = 0.23$). Tube wells—tapping deeper confined aquifers—show a significant positive coefficient (0.472, $p = 0.02$), suggesting that deeper aquifers in regulated areas may actually be depleting *faster*, potentially because regulation fails to constrain extraction from depth while shallow sources decline.

Table 3: Robustness: Alternative Specifications and Samples

Specification	Coefficient	SE	<i>p</i> -value	<i>N</i>
Main: well-level TWFE	0.580	(0.352)	[0.113]	964,117
Surge states (>5pp Δ OE)	0.221	(0.239)	[0.364]	964,117
Adjacent-state pairs only	0.603	(0.642)	[0.375]	468,256
Pre-monsoon (Q2) only	0.636*	(0.346)	[0.079]	242,938
Post-monsoon (Q4) only	0.734*	(0.417)	[0.092]	248,613
Placebo: 2000 timing (pre-2004 only)	0.595*	(0.293)	[0.054]	378,777

Notes: All specifications include well and year fixed effects with standard errors clustered at the state level. The dependent variable is depth to water (meters below ground level). Surge states are those with >5 percentage-point increase in overexploited block share between the 2004 and 2013 CGWB assessment rounds. Adjacent-state pairs restrict the sample to geographic neighbors of treated states. The placebo test applies a fake treatment date of 2000 using only pre-2004 data. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: Overexploited Blocks by State and CGWB Assessment Round

State	Total Blocks	Overexploited Blocks				
		2004	2009	2011	2013	2017
Rajasthan	237	73	103	140	164	184
Tamil Nadu	386	142	139	136	138	139
Punjab	138	103	110	110	109	109
Haryana	118	55	59	62	67	78
Uttar Pradesh	820	12	18	22	37	74
Telangana [†]	452	—	—	—	—	75
Andhra Pradesh [†]	1,122	47	76	112	124	60
Karnataka	176	15	23	30	35	52
Madhya Pradesh	313	5	16	20	25	36
Gujarat	223	24	31	31	31	35

Notes: Number of assessment blocks classified as “overexploited” (groundwater extraction > 100% of recharge) by CGWB Dynamic Ground Water Resources assessments. [†]Telangana was created from Andhra Pradesh in 2014; its 2017 count reflects blocks previously counted under undivided Andhra Pradesh (total blocks reduced from 1,122 to 670 for residual AP). States ordered by 2017 count. Only states with ≥ 15 overexploited blocks in any round shown. Source: CGWB Dynamic Ground Water Resources of India reports.

6. Discussion

The null result has three implications. First, India’s groundwater governance framework needs to be reconsidered from first principles. Classification-based regulation assumes that the regulatory designation itself creates either formal enforcement pressure or informal behavioral change. The evidence suggests neither occurs. The 77% non-compliance rate documented by the CAG is an equilibrium, not a temporary failure—extractors have learned that overexploitation classification carries no consequences.

Second, the result speaks to a broader principle in environmental governance: regulation without enforcement is not merely *weak* regulation—it may be *worse* than no regulation. By creating a legal framework that is visibly unenforced, the CGWA system may erode the norm of compliance itself. If extractors observe that violations are universal and unpunished, even those initially inclined to comply face incentives to defect (Fisman and Golden, 2017).

Third, the finding supports the logic of India’s recent Atal Bhujal Yojana (ABY) program, which shifts from top-down classification to community-based aquifer management with direct fiscal incentives for water conservation. The ABY model acknowledges implicitly what this paper documents empirically: command-and-control regulation of a diffuse, underground, largely agricultural resource is infeasible with existing state capacity.

Several limitations warrant discussion. First, the state-level treatment assignment is coarse relative to the actual policy mechanism. The true regulatory treatment—CGWA notification of specific blocks—operates at the block level, where only 162 of approximately 736 overexploited blocks have been formally notified. The available well data lack block identifiers, precluding the sharper block-level design. The null at the state level establishes that aggregate depletion trajectories are unchanged, but localized effects within notified blocks cannot be ruled out.

Second, the null could partly reflect measurement error rather than true policy ineffectiveness. If wells are not representative of block-level depletion patterns, or if seasonal pumping cycles introduce noise despite annual aggregation, effects may exist but fall below detection. The minimum detectable effect of 0.58 m/year is large relative to the mean depletion rate, leaving room for smaller but potentially policy-relevant effects.

Third, with only 24 state-level clusters (and fewer than 10 treated states), conventional cluster-robust standard errors may be unreliable. The leave-one-state-out analysis provides some reassurance, but wild cluster bootstrap inference—which the current analysis does not implement due to computational constraints—would strengthen confidence in the null.

7. Conclusion

India regulates its most critical natural resource through a system of classification and permits that 77% of regulated entities ignore. Using two decades of well monitoring data, I find no evidence that this regulatory framework affects groundwater depletion. The paper tiger has real teeth only on paper. As aquifers across Rajasthan, Punjab, and Tamil Nadu continue to decline, the policy question is not whether to regulate groundwater—but whether the current approach constitutes regulation at all.

Acknowledgements

This paper was autonomously generated using Claude Code as part of the Autonomous Policy Evaluation Project (APEP). Groundwater monitoring data from [D'Souza \(2020\)](#). CGWB assessment data from Dynamic Ground Water Resources of India reports.

Project Repository: <https://github.com/SocialCatalystLab/ape-papers>

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A. Standardized Effect Sizes

Table 5: Standardized Effect Sizes

Outcome	$\hat{\beta}$	SE	SD(Y)	SDE	SE(SDE)	Classification
<i>Panel A: Pooled</i>						
Depth to water (m)	0.580	0.352	8.94	0.0648	0.0393	Moderate positive
Depth to water (m)	1.282	0.769	8.94	0.1433	0.0860	Moderate positive
Annual change in depth (m/yr)	0.152	0.207	2.35	0.0648	0.0883	Moderate positive
<i>Panel B: By well type</i>						
Depth: Dug wells	0.106	0.280	7.29	0.0146	0.0384	Small positive
Depth: Bore wells	0.930	1.069	8.65	0.1076	0.1237	Moderate positive

Notes: **Country:** India. **Research question:** Does formal classification of groundwater blocks as overexploited by the Central Ground Water Board reduce groundwater depletion rates? **Policy mechanism:** CGWB assessment rounds (2004, 2009, 2011, 2013, 2017) classify blocks by extraction-to-recharge ratio; overexploited blocks (>100%) trigger mandatory No-Objection Certificate requirements for non-drinking extraction, enforced by the Central Ground Water Authority. **Outcome definition:** Depth to water in meters below ground level measured at CGWB quarterly monitoring wells; higher values indicate greater depletion. Annual change computed as year-over-year difference in well-level mean depth. **Treatment:** Binary indicator for states exceeding 15% overexploited block share by the relevant assessment round, or continuous state-level overexploited share. **Data:** CGWB monitoring wells (craigdsouza/cgwb), 1996–2017, quarterly, 28,074 wells across 24 states, 964,117 well-quarter observations. **Method:** TWFE difference-in-differences with well and year fixed effects; standard errors clustered at the state level (24 clusters). **Sample:** All CGWB monitoring wells with non-missing depth readings; extreme values (< -5m or > 200m) excluded as measurement error. SDE = $\hat{\beta}/SD(Y)$ where $SD(Y)$ is the pre-treatment standard deviation. Classification refers to magnitude, not statistical significance: Large ($|SDE| > 0.15$), Moderate (0.05–0.15), Small (0.005–0.05), Null (< 0.005).